Thesis
M185

Thesis
M185

Library
U. S. Naval Postgraduate School
Annapolis, Md.

[illegible]

THE [illegible] CHARACTERISTICS OF [illegible] [illegible]
[illegible]

By

Fred Earl McIntire, Jr.

An essay submitted to the Advisory Board of The School of Engineering of The Johns Hopkins University in conformity with the requirements for the degree of Doctor of Engineering.

Baltimore

1950

Thesis
M185

INDEX

Section Page

Frontpiece..............Acknowledgment

I. Introduction.............................. 1

II. General Firing Characteristics of a Thyratron.............................. 4

III. Test Circuit.............................. 8

IV. Test Results

1. Effect of ambient temperature variations..............................14

2. Effect of heater voltage variations..18

3. Effect of using D.C. for heaters.....23

4. Stability variations..................26

V. Conclusions..............................30

Bibliography..............................32

Appendix I Critical Grid Characteristic Curves.....33

Appendix II Test Readings for Temperature Effect.....36

Appendix III Test Readings for Heater Voltage Variation..............................44

Appendix IV D.C. Test Readings..........................49

Vita...57

126118

Acknowledgement

The author desires to express his gratitude to Dr. Ferdinand Hamburger, Jr., for his criticism and help without which this paper would not have been possible.

1. Introduction

Thyratrons have been used in industry over a long period of time for many applications. Since these applications have covered a wide range of power demands, thyratrons have been divided into two general groups according to their current ratings, the inert-gas-filled type and the mercury-vapor-filled type. The inert-gas-filled tubes have comparatively low current ratings of from one milliampere to four or five amperes depending on the tube design while the mercury-vapor-filled tubes, because of the higher conductivity of the mercury vapor, can carry many amperes. Because the majority of the applications of thyratrons prior to the recent war required large currents, mercury-vapor-filled tubes were used to a greater extent than the inert gas type and therefore their characteristics are more generally known. In recent years, however, due to the advent of radar and extensive airborne equipment, the demand for the low current inert gas tubes for use as inverters, servo controls, relaxation oscillators, radar modulators and grid-controlled rectifiers has increased. This growth in the number of uses of the gas thyratron has created a need for extensive research into their characteristics.

The feature of the thyratron that we are most interested in is its critical grid or control characteristic. This characteristic is a graphic representation of the grid firing voltage for various values of anode potential. For a particular type of tube, this curve is generally shown covering a band

of voltages indicating the variations of critical grid voltage for any one value of anode potential that might be encountered in the life of an individual tube and in going from one tube to another. Because of these variations, the amplitude of the grid signal is made somewhat wider than this band when it is desired to operate a circuit without making any special adjustments to accommodate one particular tube. The amplitude of the grid signal may be increased and the tube fired by introducing a peaked voltage pulse[1] on the grid at the proper time. This method possesses the advantage of confining the firing points to a very narrow time interval because of the rapid rate of rise of the peaked pulse to its maximum value. Although this method permits very precise firing of thyratrons, it is often desirable to limit the number of circuit components because of space limitations in which case it is necessary to adjust the circuit for the individual tube and thus avoid using an auxiliary means to insure precision of firing.

Since the precision of firing of individual low current thyratrons is not generally known, four common types of inert-gas-filled tubes (the 884, 885, 2051 and 2D21) were tested under static conditions. All of these tubes have a maximum allowable plate current of 300 milliamperes or less depending on their application. The temperature, D.C. anode voltage and A.C. heater voltage were considered as the controlled parameters for the study. Each parameter was varied over a range considered consistent with variations that might be expected under uncontrolled operating conditions. In addition to these tests, the effect of D.C. heater potential on the

stability of the firing characteristics was studied. In this study, stability means the maximum variation of the critical grid voltage from the average critical grid voltage at any one anode potential.

In order to predict the performance of any thyratron, one must not only know the static characteristics of a tube but also its frequency performance. The effect of frequency on the firing characteristics of small thyratrons has been analysed by H.M. Wittenberg[illegible]. He has concluded, as a result of his tests, that, at high audio frequencies, the firing characteristic shifts negatively with increasing frequency as a result of the grid-anode capacitance and may shift negatively with increasing gas pressure because of increased ionization efficiency. Two of the tubes used in arriving at these conclusions were the 884 and 2051 which are also discussed in this paper. It is believed that one is able to predict the performance of individual tubes of the 884, 885, 2051 and [illegible] types with a reasonable degree of accuracy by using the results of H.M. Wittenberg in conjunction with this paper.

II. General Firing Characteristics of a Thyratron

The firing characteristics of a thyratron depend on several factors, the most important of which are the tube geometry, the gas or vapor used and the gas pressure. Whether inert gas or mercury vapor is used depends on the power requirements of the particular service since inert gas tubes have a lower current rating than the mercury vapor type. Since low current thyratrons were selected for this study, the influence of these factors on inert-gas-filled tubes will be discussed here. The firing characteristics of mercury-vapor-filled tubes differ little from those of the inert-gas-filled type except as to temperature effect.

In order to understand how the factors mentioned above affect the firing characteristics of the thyratron, it is well to briefly describe thyratron operation. The starting of an arc discharge between the cathode and anode of a gas tube depends on the formation of positive ions in the inter-electrode space. The positive ions are formed by the bombardment of the gas molecules by the electrons emitted by the cathode.

When an anode potential is applied to a gas tube, a field is set up and the electrons emitted by the cathode move toward the anode. The distance that they can move before colliding with a gas molecule is the mean free path in the gas. If the field that the electrons are subjected to is sufficiently strong, they have sufficient energy to

ionize the gas molecules with which they collide, and a positive ion results. In this case, there are now two electrons free to move until they build up enough energy to ionize two more molecules. This process is cumulative and will occur until breakdown. At breakdown, theoretically, as many positive as negative charges will exist in the discharge region now called the "plasma" portion of the arc. At this time there is then no retarding field that tends to restrict current flow. Paschen's Law states that this breakdown voltage is a function of the product of the pressure within the tube and the inter-electrode spacing.

In a thyratron, as in any other gas tube, the same phenomenon occurs. Here a grid is inserted that almost completely shields the cathode from the anode so that a small negative voltage on the grid will neutralize the effect of the field caused by the anode potential. When the grid is made more positive than a critical value, ionization of the gas molecules occurs and the tube behaves as described above. When breakdown occurs, the grid no longer has control since it is immersed in the plasma and separated from this by a sheath of positive ions. This sheath is a thin, well-defined region of high electric field containing almost no electrons[3].

In an inert-gas-filled thyratron the gas pressure does not change very much with ordinary ambient temperature

variations, and, as a result, the velocity of the molecules of gas remains practically constant. Therefore, although the number of collisions between molecules and electrons may increase slightly, there is no noticeable increase in the negative grid voltage necessary to keep the tube from firing. However, during the life of an individual tube, some of the gas is absorbed by the tube walls thus decreasing the number of gas molecules and changing the critical grid characteristic. Generally, it can be said that, if all voltages are kept constant, ambient temperature changes will not affect the critical grid voltage for any one anode potential over a short interval of time. It is not inconceivable however, that, if the ambient temperature is raised sufficiently, the cathode temperature will be changed and the electron emission current increased in accordance with Dushman's equation[3]. This would necessitate a more negative grid voltage to prevent breakdown and therefore shift the control characteristic.

Since the ambient temperature, theoretically, does not noticeably affect the critical grid characteristics of an inert gas thyratron in normal operation, we must look for other factors that might affect a tube's stability or shift its control characteristic. By tube stability is meant the variation of the critical grid potential from an average value. The principal cause of a variation in the control characteristic of a single inert gas thyratron appears to be a change in the electron emission properties of the cathode.

The electron emission of thermionic cathodes at first was believed to be only a function of the absolute temperature and the cathode material, but later Schottky[3] found that it also depended on the electric field at the surface of the cathode caused by the anode potential. Schottky's formula gives slightly higher values of electron emission currents than the thermionic emission equations of Dushman or Richardson[3]. However, the "Schottky effect", as it is called, is not large enough to have any importance in the practical application of thyratrons.

An increase in the electron emission current requires that a more negative grid potential be applied to prevent breakdown because of the increased number of electrons bombarding the gas molecules. Since cathodes are designed to maintain nearly constant emission characteristics during a tube's life, the emission current for a single anode voltage can only be changed by a change in the heater power which varies the cathode temperature. If an A.C. heater voltage is used, the heat capacity of modern cathodes is such that they have an extremely small change of temperature even though the heating effect of the heater varies during a cycle. Therefore, the only manner in which the emission current of the cathode can be changed is by varying the average power to the heater. This change of heater power does not affect the tube's stability but merely shifts the control characteristic. If the cathode temperature varied during a cycle of A.C. heater voltage input, the

stability of the tube would be affected by A.C. and it would be desirable to use only D.C. for the heater to keep the heater power and thus the cathode temperature constant over even the shortest period of time.

It can be concluded from this discussion that the only parameter that must be controlled for precise firing of an inert gas thyratron is the power to the heaters.

III. Test Circuit

In conducting this investigation, the test circuit shown in Fig. 1 was used. The grid resistance, R_g, inserted to limit the grid current, was, in all cases, that recommended by the manufacturer, and the load resistance, R_L, was set at 10,000 ohms. It was found necessary to insert an inductance, L, in series with the plate load to prevent the voltage surges at the higher values of plate voltage, E_p, from igniting the tube when the plate power supply was initially turned on.

A 200-400 volt regulated power supply was used for the plate supply instead of a simple power supply because its regulation prevented changes in the A.C. supply voltage from affecting the investigation. The ripple voltage of the plate power supply was less than 25 millivolts. An 8000 ohm slide wire resistor was connected across this power source to obtain the desired variation of anode voltage.

A 45 volt battery was used to supply the grid voltage. Two variable resistors were connected across the battery to control the grid voltage. One, a one megohm resistor, was used as the rough voltage control, and the other, a 50,000 ohm resistor, was the fine control. The rough voltage control was set approximately one volt more negative than the critical grid voltage for a definite anode potential, and then the fine control was varied until the tube ignited.

For the measurement of the critical grid voltage,

two voltmeters were used. One of these voltmeters measured a fixed voltage supplied by a 45 volt battery and a potentiometer circuit. The other measured the voltage difference between this fixed voltage and the voltage supplied by the grid supply battery. The fixed voltage was generally set within one volt of the expected grid firing value, and this permitted the second voltmeter to read voltages to two decimal places.

The heater voltage was supplied by a variac and a filament transformer from the regular A.C. supply line. The variac was used to control the heater voltage within very narrow limits.

In order to obtain constant ambient temperatures, the circuit shown in Fig. 2 was used. The heating element was Nichrome wire which was located in the bottom of a temperature controlled space. The temperature controlled space consisted of two wooden boxes, one within the other, lined with asbestos insulation. A low speed fan was used to circulate the air inside the space. The current to the heating element was controlled by a relay operated by the plate current of a 2016 tube. This tube was convenient to use since its grid cut-off voltage was approximately -20 volts and therefore the plate current could be easily turned on or off by the circuit arrangement used. When the temperature was below that desired, the grid bias was -10 volts which permitted the plate current to flow and close the relay. This allowed sufficient current to flow

through the lamp bank of three 150 watt lamps to heat the temperature controlled space. When the temperature had reached the desired value, the grid was returned to ground through the mercury thermostat and the tube cut-off. This opened the relay and a 40 watt lamp was thus connected in series with the Nichrome wire, increasing the resistance and reducing the current below that required for heating the space. By this means the temperature was kept within ½°C of the desired value.

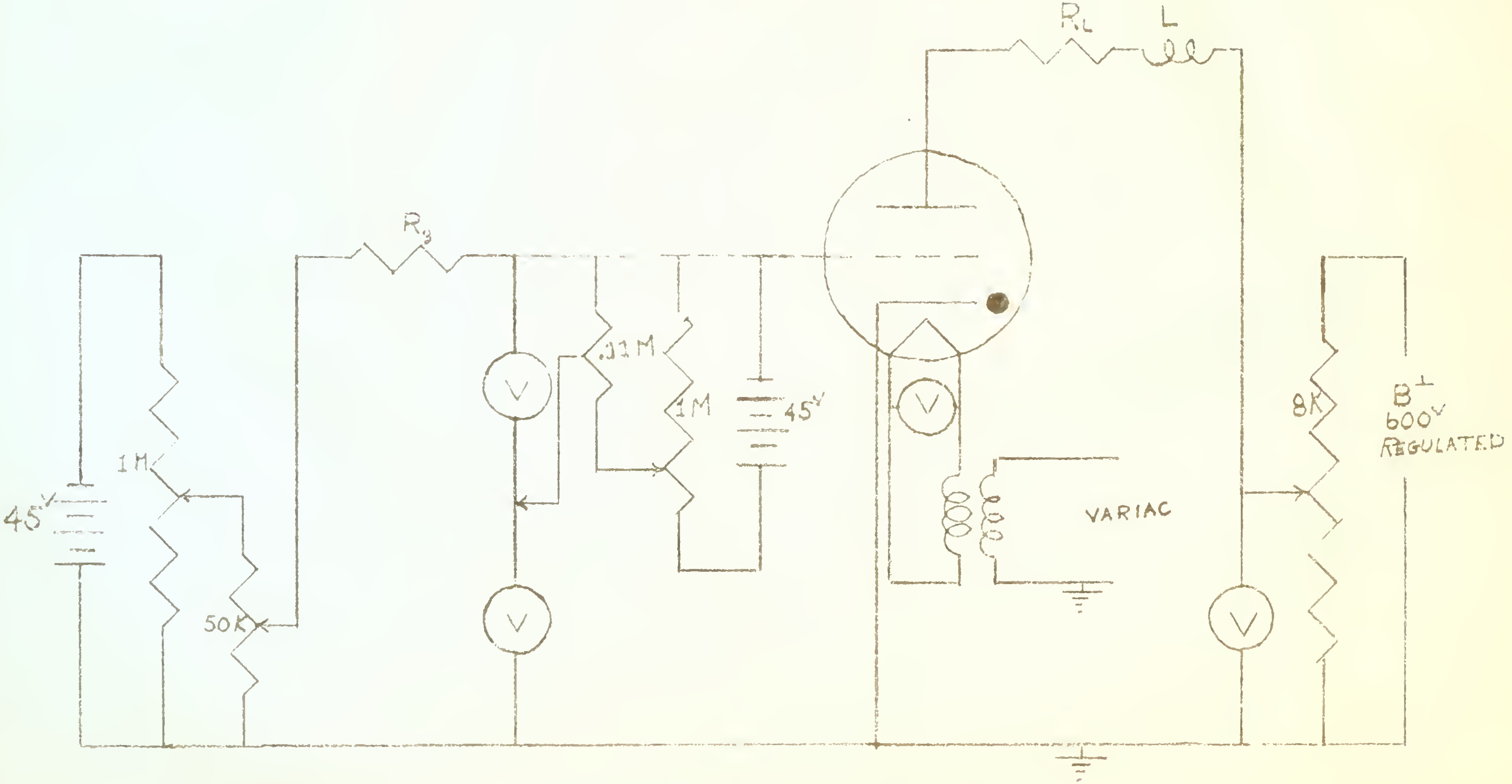


Fig. 1 - Test Circuit

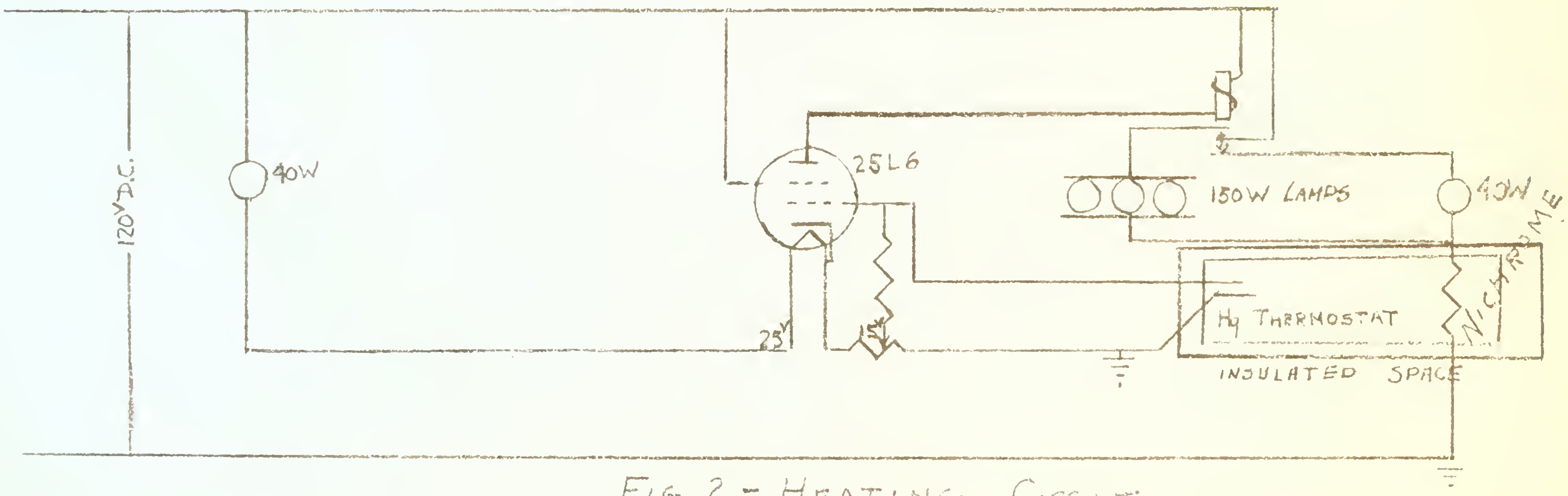


FIG. 2 - HEATING CIRCUIT

IV. Test Results

1. Effect of Ambient Temperature Variations

In order to determine what effect, if any, ambient temperature variations might have on the grid control characteristics of individual tubes, the data shown in Appendix II were taken at three temperatures, 40, 50, and 60°C. The tubes were kept in the temperature controlled space, previously described, for thirty minutes to insure uniform ambient temperature conditions for all readings.

Tables I and II are compilations of the average readings of the critical grid voltage for 10 and 20°C changes in ambient temperature for the 884, 885, 2051 and 6D4. The tables indicate that the majority of the changes of the critical grid voltage were in the negative direction for increases in ambient temperature. For a 10°C increase, 85% of the readings noted were in a negative direction while for the 20°C increase, 80% of the readings were in this direction. These changes, however, are not conclusive evidence of any ambient temperature effects on the grid control characteristic. If we analyze the problem more closely, we must refer to Table VI which indicates the difference between maximum and minimum readings in a series of ten readings at various values of anode potential.

Table VI indicates that the random variations are of the order of 0.05 volts for the 884 and 885 tubes. This is

approximately the same value as the average ambient temperature variation of 0.054 volts for the 884 and slightly larger than that of 0.025 volts for the 6D4. In addition to this, the variations noted for these two tubes in Table I are of a random nature. Therefore it must be concluded that the control characteristics of the 884 and 6D4 are not affected by ambient temperature variations.

For the 885 and the 2051, we do not need to refer to Table VI. From Tables I and II it is evident that the variations noted are of a random nature. In Table I, if there is a change in the negative sense in going from 40° to 50°C then a positive change is shown in going from 50° to 60°C and vice versa for each tube. This is true at all anode potentials listed.

As a result of these tests, it can be said that the 884, 885, 2051 and 6D4 are not affected by changes in ambient temperature in the range of temperature that one can expect to encounter in normal operation.

TABLE 3

COMPARATIVE VARIATIONS OF CRITICAL E_c FOR TEMPERATURE CHANGES OF 10°C

Tube	884		885		2051		[illegible]	
T(°C)	40/50°	50/60°	40/50°	50/60°	40/50°	50/60°	40/50°	50/6
E_p (volts								
50	-.032	-.005	-.020	.109	-.071	.002	-.007	-.046
75	-.046	.007	.003	-.004	-.080	.011	.004	-.092
100	-.031	.001	.059	-.010	.012	-.030	-.020	-.008
125	-.007	-.010	.042	-.046	.020	-.032	-.004	-.002
150	.073	-.136	.004	-.010	.006	-.027	-.040	-.010
175	.056	-.144	.152	-.044	.010	-.011	.040	-.032
200	.004	-.009	.132	-.040	.030	-.024	.000	-.016
220			.021	-.140				
225	-.070	-.037			.024	-.039	.060	-.042
240			.000	-.350				
250	-.035	.003			.053	-.020	-.050	.081
275	.009	-.094			.017	-.011	-.104	.110
300	.000	-.060			.009	-.027	-.030	.011
AVG	.003	-.002	.047	-.095	.009	-.017	-.024	-.011

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
				[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
		[illegible]		[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2. Effect of Heater Voltage Variations

For this test the heater voltage of each tube was varied 0.2 volts either side of the rated voltage at a constant ambient temperature of 50°C. This change was well within the limits prescribed by the manufacturer. Readings were taken successively at each voltage and repeated to insure the least change in circuit and other conditions.

As expected, a change in heater voltage has a very definite effect on the critical grid characteristics. As the heater voltage was decreased, the critical grid voltage became more positive and vice versa. This demonstrated that the number of electrons being emitted by the cathode was increasing or decreasing as the heater power was being varied.

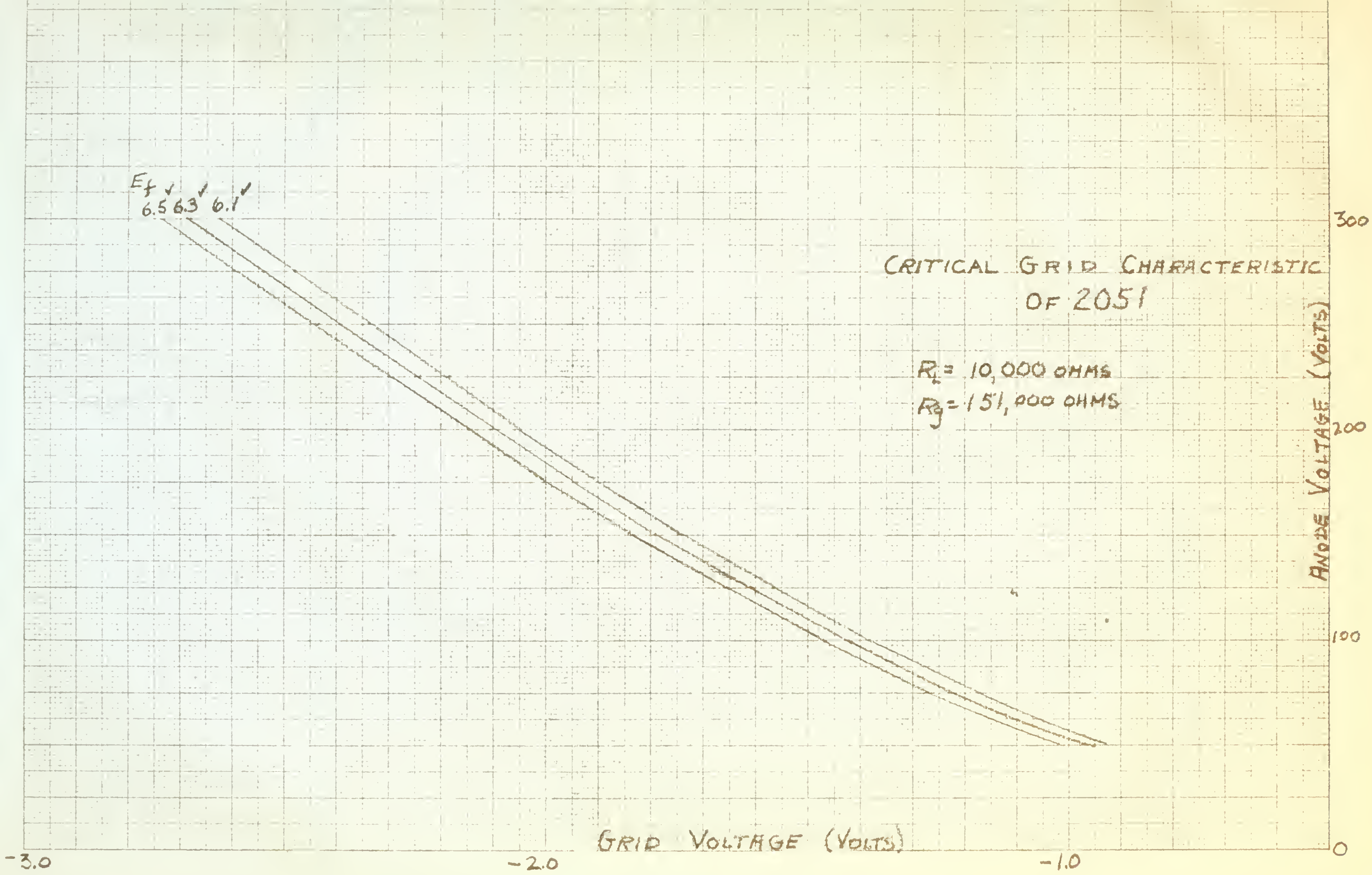
Tables III and IV show the effect of both positive and negative variations of heater voltage. The 884 and 885 exhibited the greatest change in the critical grid voltage for an equivalent change in heater power. On the average, corresponding changes in the heater power of the 884 and 885 resulted in equivalent shifts of the grid control characteristic. This shift was on the order of 0.03 volts for a change of 0.22 watts in heater power. The critical grid voltages of the 2051 and the C1B varied approximately 0.06 volts for the same heater power variation.

These changes of the grid control characteristic do not appear to be of a random nature since the maximum variation of any reading in Appendix III is approximately

0.02 volts from the average. It is reasonable to expect that the averages for the various heater voltages would differ by less than this value if the heater power changes had no effect on the control characteristics. In addition, Tables III and IV show that changes of the critical grid potential of the 2051 and 6Q5 tubes were always in the same direction and approximately the same value for all anode potentials.

The results for the 884 and 885 indicate that there is a slight increase in the effect of heater power variations as the plate potential is increased. At lower anode voltages, apparently some of the electrons emitted by the cathode never gain enough energy to ionize the gas molecules but as the anode voltage is increased the percentage of these electrons decreases and a greater negative grid potential is required to prevent breakdown. The 2051 and the 6Q5 did not show this variation.

All four tubes show a variation of control characteristics with a change of heater power. Therefore when precise firing is required, the tube should have a regulated voltage supply for its heater.



CRITICAL GRID CHARACTERISTIC OF 2051

R_L = 10,000 OHMS
R_g = 151,000 OHMS

TABLE III

COMPARISON OF VARIATIONS OF CRITICAL E_g FOR E_f OF ±.2^V

Tube	884		885		2051		2050	
E_f(volts)	-.2^V	.2^V	-.2^V	.2^V	-.2^V	.2^V	-.2^V	.2^V
E_p(volts)								
25			-.035	.109	-.042	.064	-.030	[illegible]
50	-.066	.055	-.104	.134	-.068	.076	-.045	.048
75			-.103	.148	-.056	.059	-.040	.057
100	-.074	.050	-.174	.150	-.060	.051	-.045	.050
125			-.165	.172	-.047	.045	-.050	.061
150	-.077	.032	-.133	.134	-.045	.040	-.044	.041
175			-.155	.190	-.050	.065	-.041	.055
200	-.061	.145	-.171	.248	-.056	.059	-.041	.032
220			-.274	.368				
225					-.067	.059	-.065	.061
240			-.535	.267				
260	-.109	.109			-.035	.059	-.055	.034
275					-.060	.047	-.052	.039
300	-.107	.105			-.067	.054	-.050	.045
AVG	-.084	.095	-.160	.200	-.049	.054	-.044	.041

TABLE IV

AVERAGE VARIATION OF CRITICAL E_g FOR 0.1^V CHANGE OF E_f FROM RATED VALUE

Tube	884	885	2051	C5B
E_p(volts)				
25		.055	.020	.016
50	.031	.064	.024	[illegible]
75		.077	.022	.019
100	.033	.083	.025	[illegible]
125		.086	.023	.016
150	.041	.092	.0255	.022
175		.094	.027	.020
200	.052	.104	.028	.010
220		.160		
225			.029	.026
240		.190		
250	.054		.027	.022
275			.027	.018
300	.057		.028	.020
AVG	.045	.101	.026	.021

3. Effect of Using D.C. For Heaters

This test was conducted at 50°C to determine if there was any difference in the grid control characteristics when D.C. was used for the heaters instead of A.C. At each anode potential at which the measurements were made, the readings in Appendix IV were taken first with A.C. and then D.C. heater voltage. Table V shows the averages of these readings. It was thought in conducting this test that the heaters of the tubes might have undesirable reactances which would introduce a phase difference between the voltage and current. This would mean that with A.C. the heaters would have less heating power than with D.C. for the same voltage input. If the heating effect was greater with D.C., then the grid potential would have to be more negative to prevent breakdown than in the A.C. case.

For the 884 and 885 the average variation was in the wrong direction showing that with an A.C. heater supply a more negative grid voltage was required. The 2051 and 6Q5G had variations in the right direction but of such a value that they were very small as compared to the random variations discussed in the next section. An additional fact supporting the conclusion that A.C. and D.C. heater voltages do not differ in their effect on the critical grid characteristics of these tubes is the nature of the variation for the 884 and 6Q5G shown in Table V. The table shows for these two tubes that there are as many changes of the control

voltage in the negative direction as there are in the positive direction. Therefore it may be concluded that the heaters of these thyratrons are so designed that they may be used with A.C. or D.C. heater voltage without any noticeable effect on the control characteristics of the tube.

TABLE V

VARIATION OF CRITICAL E_c DUE TO USE OF A.C. AND D.C.

Tube	884	885	2051	[illegible]
E_p(volts)				
50	.027	-.034	.001	-.022
100	-.002	-.082	.007	-.002
150	.030	-.036	.009	.016
200	-.007	-.012	.020	.015
250	.010	-.022	.020	-.005
300			.000	-.020
AVG	(-).012	(-).035	.010	.005

Note: Negative sign indicates A.C. more negative

4. Stability Variations

In considering a thyratron for precise timing applications, the variations of the critical grid voltages from the average due to unexplainable reasons must be taken into account as well as those due to definite causes. Table VI shows the maximum variation of the critical grid voltage noted in any series of readings. For example, in a series of ten readings at constant anode and heater potential and constant temperature the difference between the maximum and minimum critical grid voltage readings was taken as the maximum variation for that set.

The maximum variation of critical grid voltage was 0.15 volts at a plate voltage of 300 volts for the 6Q5. This represented a variation of 0.8% of the average control voltage for this plate potential. However, the other readings for this tube indicate this value to be in error. The maximum variations of the other tubes range from 3% for the 2051 down to 0.3% for the 885. With the exception of the 2051, the variations are all less than 1% of the average grid control voltage. This variation appears to be independent of anode potential being of the same order of magnitude for all readings of any particular tube.

When comparing the effect of D.C. and A.C. heater voltage on the grid control characteristics, particular attention was paid to the variations from the average critical grid voltage. It was thought that A.C. might introduce

electrostatic or magnetic fields that would change the stability of the tube firing characteristics. This was not found to be the case since the stability of the tube was seemingly unaffected by a change from A.C. to D.C. for the heater supply.

Generally, it can be said that, for all the tubes tested, the maximum variation of critical grid voltage from random causes is less than 0.06 volts.

TABLE VI

MAXIMUM VARIATIONS OF CRITICAL E_c NOTED IN ANY SERIES OF READINGS

Tube	884	885	2051	2050
E_p(volts)				
50	.05	.02	.01	.03
75	.03	.02	.02	.04
100	.04	.02	.04	.04
125	.04	.01	.03	.04
150	.06	.01	.01	.04
175	.05	.01	.02	.04
200	.04	.01	.03	.05
225	.04		.02	.05
250	.05		.03	.06
275	.03		.03	.05
300	.05		.02	.10
		240^{V} .05		
AVG	.044	.02	.024	.050

V. CONCLUSIONS

The following conclusions can be drawn concerning the stability of the small thyratrons discussed in this paper:

1. Under uncontrolled operating conditions, these tubes can be expected to operate within 0.2 volts of the desired critical grid voltage in the ambient temperature range of 40-60°C.
2. Under controlled operating conditions, these tubes will operate within less than 0.1 volts of the desired critical grid voltage.
3. In designing a thyratron circuit for control purposes care must be exercised to isolate the tube from external magnetic or electric influences.
4. Under uncontrolled operating conditions the tetrode exhibits less variation than the other types, approximately 0.05 volts.
5. A variation of the heater voltage causes a greater shift in the critical grid characteristics of the small thyratrons than random effects, ambient temperature changes or changes from A.C. to D.C. heater supply.
6. These tubes can be used with either A.C. or D.C. heater supply without any noticeable change in the maximum variation of the critical grid voltage from the average.

Table VII indicates the comparative variations of these tubes. The voltages shown in the TOTAL column are considered to be the maximum variations that will be encountered in these thyratrons for uncontrolled operating conditions.

TABLE VII. Variation of Critical E_g Due to All Causes

Tube	884	885	2051	6D3
Variation				
$E_f \pm 0.1$ volts	.048	.101	.026	.021
Random	.044	.020	.024	.052
TOTAL	.092	.121	.050	.073

Note: Variation of E_g in volts.

BIBLIOGRAPHY

1. Pulse Response of Grid Control Circuits, C. Herbert Gleason and Carl Beckman. Institute of Radio Engineers, Vol.34, February 1946, 71P

2. Frequency Performance of Thyratrons, Hubert D. Wittenberg. Publication No. ST-337, Tube Division, Radio Corporation of America, Lancaster, Pa., December 1946

3. Electronics and Electron Tubes(book), E. D. McArthur. John Wiley and Sons, Inc., New York, N. Y., 1936, pp. 15-

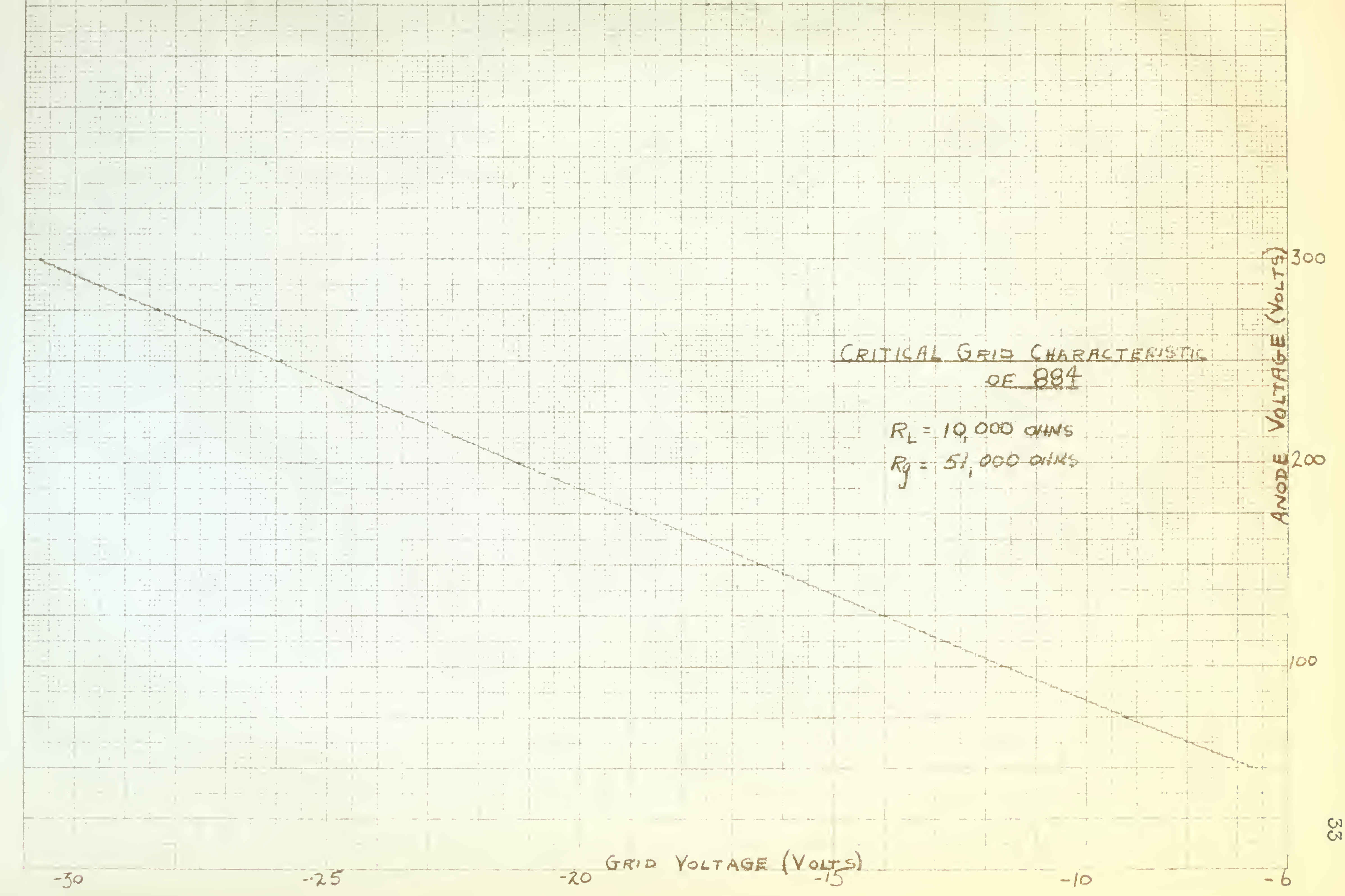
4. Electronics (book), Jacob Millman and Samuel Seely. McGraw-Hill Book Co., Inc., New York, N. Y., 1941 Chap. 9 - 11.

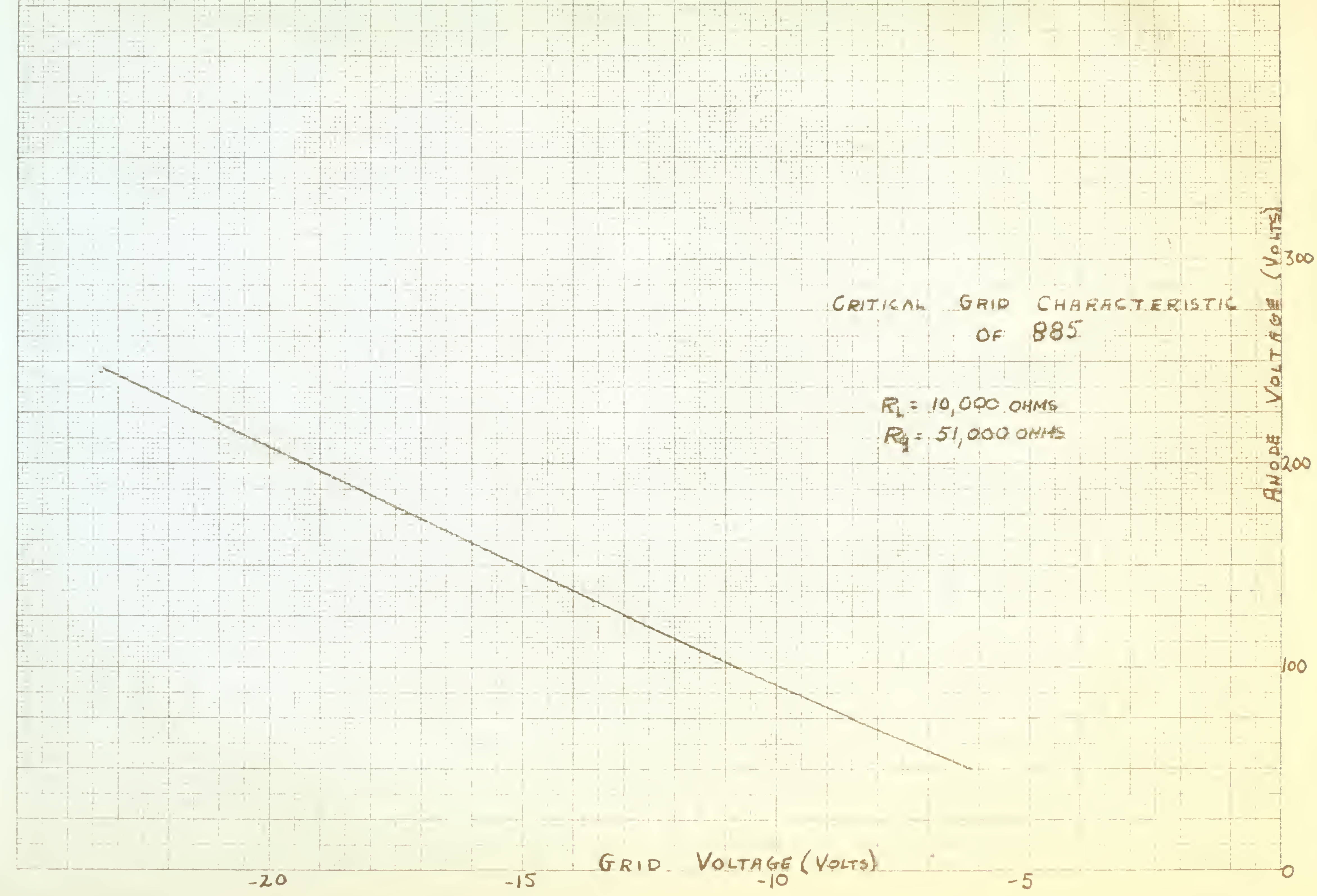
5. Radio Engineers Handbook, F. E. Terman. McGraw-Hill Book Co., Inc., New York, N. Y., 1943

6. Electrical Engineers Handbook, H. Pender and K McIlwain. John Wiley and Sons, Inc., New York, N. Y.

APPENDIX I

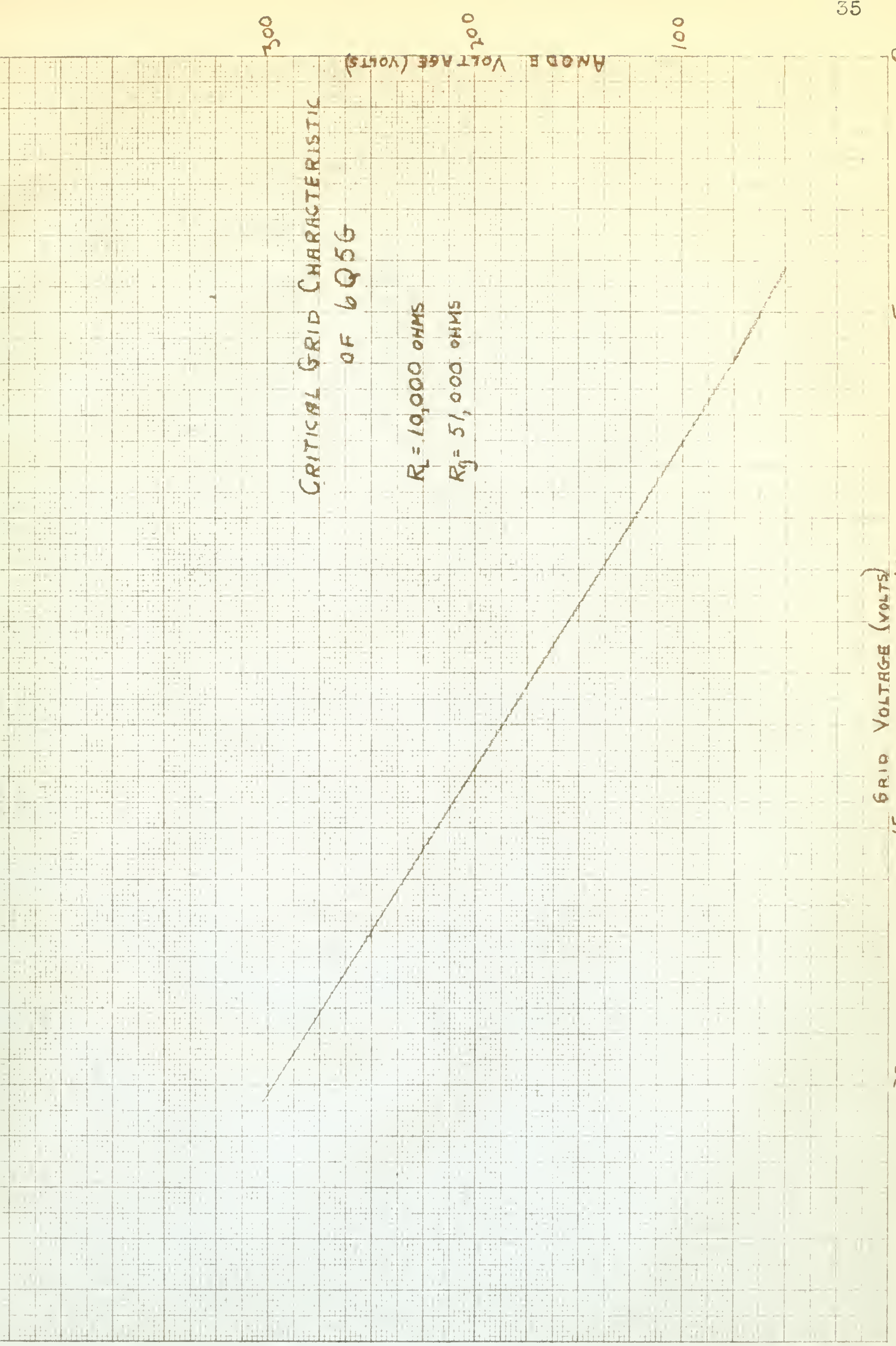
Critical Grid Characteristic Curves


CRITICAL GRID CHARACTERISTIC
OF 884
R_L = 10,000 OHMS
R_g = 51,000 OHMS
ANODE VOLTAGE (VOLTS)
300
200
100
GRID VOLTAGE (VOLTS)
-30
-25
-20
-15
-10
-6



CRITICAL GRID CHARACTERISTIC
OF 885

R_L = 10,000 OHMS
R_g = 51,000 OHMS


CRITICAL GRID CHARACTERISTIC
OF 6Q5G
R_L = 10,000 OHMS
R_g = 51,000 OHMS
ANODE VOLTAGE (VOLTS)
300
200
100
0
GRID VOLTAGE (VOLTS)
-5
-10
-15
-20

APPENDIX II

Test Readings Taken to Determine Effect of Temperature

VARIATION OF CRITICAL E_g WITH TEMPERATURE

For the 884

E_p (volts)	50			75			100		
T (°C)	40	50	60	40	50	60	40	50	60
1	6.64	6.65	6.66	9.22	9.24	9.24	11.71	11.70	11.70
2	6.61	6.64	6.65	9.20	9.23	9.23	11.71	11.70	11.70
3	6.64	6.67	6.66	9.21	9.23	9.23	11.71	11.70	11.70
4	6.60	6.65	6.67	9.23	9.22	9.22	11.70	11.70	11.70
5	6.64	6.64	6.66	9.21	9.22	9.21	11.71	11.70	11.70
6	6.61	6.65	6.66	9.20	9.23		11.68	11.71	
7	6.61	6.67	6.66	9.20	9.23		11.69	11.70	
8	6.61	6.67	6.67	9.23	9.24		11.68	11.70	
9	6.63	6.68	6.67	9.22	9.24		11.70	11.70	
10	6.62			9.23	9.24		11.71	11.70	
Avg.	6.621	6.656	6.661	9.215	9.232	9.226	11.700	11.701	11.700
Corr.	-.025	-.028	-.028	-.031	-.002	-.002	-.030	0	-.000
E_g (volts)	6.596	6.628	6.633	9.184	9.230	9.223	11.670	11.701	11.700
		Avg. 6.619			9.212			11.690	

E_p	125			150			175		
T	40	50	60	40	50	60	40	50	60
1	14.10	14.11	14.11	16.78	16.72	16.85	18.90	18.90	19.00
2	14.10	14.09	14.12	16.78	16.73	16.84	18.90	18.85	19.00
3	14.08	14.10	14.11	16.79	16.71	16.85	18.90	18.85	19.00
4	14.10	14.11	14.11	16.80	16.72	16.85	18.90	18.85	19.00
5	14.12	14.11	14.12	16.81	16.70	16.83	18.90	18.85	19.00
6	14.08			16.79	16.70		18.90		
7	14.07			16.80	16.71		18.90		
8	14.10			16.80	16:70		18.90		
9	14.12			16.80	16.73		18.90		
10	14.10			16.78	16.69		18.90		
Avg.	14.097	14.104	14.114	16.793	16.711	16.844	18.900	18.860	19.00
Corr.	-.025	-.025	-.025	-.035	-.031	-.031	-.025	-.029	-.025
E_g (volts)	14.072	14.079	14.089	16.758	16.680	16.813	18.875	18.831	18.975
Avg.		14.080			16.750			18.894	

VARIATION OF CRITICAL E_g WITH TEMPERATURE FOR THE 884

E_p (volts)		200			225			250	
T (°C)	40	50	60	40	50	60	40	50	60
1	21.18	21.18	21.25	23.56	23.55	23.57	26.00	26.05	25.95
2	21.18	21.18	21.25	23.53	23.56	23.58	26.05	26.05	26.00
3	21.16	21.18	21.26	23.56	23.54	23.58	25.95	25.95	26.00
4	21.15	21.16	21.25	23.56	23.56	23.59	25.95	26.00	25.95
5	21.15	21.17	21.26	23.55	23.56	23.60	25.95	25.95	26.00
6	21.16	21.15		23.56		23.59	25.90	26.00	
7	21.16	21.15		23.54		23.60	25.95	25.95	
8	21.17	21.14		23.56		23.61	25.95	25.95	
9	21.18	21.16		23.54		23.60	25.95	26.00	
10	21.16			23.56		23.61	25.90	26.00	
Avg.	21.165	21.161	21.254	23.552	23.554	23.593	25.955	25.990	25.990
Corr.	.002	.002	-.002	-.023	-.023	-.025	-.025	-.025	-.025
E_g (volts)	21.167	21.163	21.252	23.529	23.531	23.568	25.930	25.965	25.965
Avg.		21.194			23.542			25.953	

E_p		275			300	
T	40	50	60	40	50	60
1	28.30	28.28	28.39	30.70	30.65	30.75
2	28.32	28.31	28.40	30.70	30.70	30.75
3	28.31	28.30	28.40	30.70	30.65	30.75
4	28.32	28.31	28.40	30.70	30.70	30.75
5	28.30	28.30	28.42	30.65	30.65	30.75
6	28.31			30.70	30.65	
7	28.31			30.65	30.70	
8	28.32			30.70	30.70	
9	28.30			30.60	30.70	
10	28.30			30.70		
Avg.	28.309	28.300	28.404	30.68	30.678	30.75
Corr.	-.005	-.005	-.015	-.029	-.029	-.033
E_g	28.304	28.295	28.389	30.651	30.649	30.717
Avg.		28.329			30.672	

Note: All grid voltages are negative.

VARIATION OF CRITICAL E_g WITH TEMPERATURE FOR THE 885

E_p(volts)		50			75			100	
T (°C)	40	50	60	40	50	60	40	50	60
1	6.15	6.18	6.16	8.55	8.55	8.57	10.81	10.76	10.76
2	6.15	6.18	6.17	8.56	8.54	8.57	10.82	10.75	10.77
3	6.15	6.18	6.17	8.56	8.55	8.58	10.82	10.76	10.77
4	6.14	6.17	6.17	8.54	8.55	8.57	10.82	10.76	10.77
5	6.15	6.18	6.17	8.55	8.55	8.58	10.81	10.77	10.78
Avg.	6.148	6.178	6.168	8.552	8.548	8.574	10.816	10.760	10.770
Corr.	.003	.001	.002	-.023	-.022	-.024	-.007	-.003	-.003
E_g(volts)	6.151	6.179	6.170	8.529	8.526	8.550	10.809	10.757	10.767
Avg.		6.167			8.535			10.777	

E_p		125			150			175	
T	40	50	60	40	50	60	40	50	60
1	12.95	12.90	12.95	15.12	15.08	15.09	17.53	17.36	17.40
2	12.95	12.89	12.95	15.12	15.08	15.10	17.52	17.36	17.41
3	12.95	12.90	12.95	15.12	15.08	15.09	17.53	17.36	17.41
4	12.94	12.90	12.94	15.12	15.09	15.09	17.53	17.35	17.41
5	12.95	12.90	12.94	15.12	15.09	15.10	17.52	17.36	17.40
Avg.	12.948	12.898	12.946	15.12	15.084	15.094	17.526	17.358	17.406
Corr.	- .017	-.015	-.017	-.016	-.014	-.014	-.021	-.011	-.015
E_g	12.931	12.883	12.929	15.104	15.070	15.080	17.505	17.347	17.391
Avg.		12.914			15.085			17.369	

E_p		200			220			240	
T	40	50	60	40	50	60	40	50	60
1	19.33	19.19	19.45	21.04	21.02	21.15	23.25	23.25	23.60
2	19.33	19.20	19.45	21.04	21.02	21.16	23.25	23.25	23.65
3	19.34	19.20	19.46	21.03	21.01	21.15	23.25	23.25	23.60
4	19.34	19.19	19.45	21.04	21.01	21.16	23.25	23.25	23.65
5	19.34	19.20	19.46	21.03	21.01	21.16	23.25	23.25	23.60
Avg.	19.336	19.196	19.454	21.036	21.014	21.156	23.25	23.25	23.62
Corr.	-.008	0	-.018	.002	0	.002	-.02	-.02	-.04
E_g	19.328	19.196	19.436	21.035	21.014	21.154	23.23	23.23	23.58
Avg.		19.320			21.068			23.350	

Note: All grid voltages are negative.

VARIATION OF CRITICAL E_g WITH TEMPERATURE FOR THE 6J5G

E_p (volts)	50			75			100		
T (°C)	40	50	60	40	50	60	40	50	60
1	4.15	4.21	4.22	5.88	5.86	5.98	7.55	7.56	7.62
2	4.17	4.21	4.22	5.87	5.89	5.97	7.54	7.55	7.60
3	4.16	4.23	4.21	5.87	5.87	5.95	7.53	7.58	7.61
4	4.16	4.22	4.22	5.88	5.87	5.96	7.55	7.57	7.61
5	4.16	4.21	4.21	5.89	5.87	5.96	7.53	7.57	7.61
6	4.16	4.21	4.21	5.88	5.88	5.96	7.56	7.59	7.61
7	4.14	4.20	4.21	5.88	5.87	5.96	7.56	7.58	7.62
8	4.16	4.22	4.22	5.88	5.87	5.99	7.57	7.59	7.62
9	4.16	4.24	4.21	5.88	5.88	5.96	7.56	7.59	7.61
10	4.14		4.21	5.88	5.88	5.95	7.55	7.59	7.62
Avg.	4.156	4.217	4.214	5.879	5.874	5.964	7.550	7.577	7.612
Corr.	.002	.002	-.001	-.013	-.012	-.017	-.022	-.023	-.026
E_g (volts)	4.158	4.167	4.213	5.866	5.862	5.947	7.528	7.554	7.586
Avg.		4.179			5.892			7.559	

E_p	125			150			175		
T	40	50	60	40	50	60	40	50	60
1	9.10	9.08	9.21	10.68	10.72	10.75	12.26	12.21	12.30
2	9.12	9.09	9.17	10.68	10.71	10.74	12.26	12.22	12.29
3	9.10	9.12	9.16	10.68	10.74	10.76	12.27	12.23	12.29
4	9.09	9.10	9.20	10.68	10.73	10.76	12.25	12.24	12.28
5	9.09	9.09	9.20	10.68	10.74	10.75	12.25	12.23	12.28
6	9.09	9.09	9.21	10.68	10.73	10.74	12.28	12.23	12.28
7	9.10	9.09	9.20	10.70	10.74	10.73	12.29	12.24	12.27
8	9.08	9.11	9.20	10.68	10.75	10.73	12.27	12.20	12.27
9	9.08	9.08	9.20	10.69	10.73	10.73	12.27	12.23	12.27
10	9.08	9.11	9.21	10.69	10.74	10.73	12.28		12.28
Avg.	9.093	9.096	9.196	10.684	10.733	10.742	12.268	12.226	12.281
Corr.	.005	.005	-.030	0	-.003	-.002	-.003	-.001	-.004
E_g (volts)	9.098	9.103	9.166	10.684	10.730	10.740	12.265	12.225	12.277
		9.122			10.718			12.256	

VARIATION OF CRITICAL E_g WITH TEMPERATURE FOR THE 6Q5G

E_p (volts)	200			225			250		
T (°C)	40	50	60	40	50	60	40	50	60
1	13.87	13.81	13.84	15.39	15.33	15.40	17.07	17.13	17.06
2	13.85	13.85	13.84	15.36	15.32	15.39	17.09	17.14	17.07
3	13.83	13.86	13.87	15.39	15.31	15.36	17.09	17.12	17.06
4	13.86	13.85	13.87	15.40	15.32	15.39	17.10	17.15	17.06
5	13.84	13.85	13.87	15.38	15.31	15.39	17.09	17.16	17.08
6	13.86	13.85	13.88	15.37	15.34	15.37	17.10	17.17	17.04
7	13.85	13.84	13.88	15.36	15.34	15.36	17.09	17.18	17.04
8	13.85	13.84	13.88	15.37	15.33	15.38	17.10	17.18	17.04
9	13.84	13.85	13.86	15.37	15.34	15.35	17.10	17.15	17.03
10	13.85		13.87	15.37	15.32	15.35	17.10		17.06
Avg.	13.850	13.845	13.866	15.376	15.325	15.374	17.093	17.152	17.054
Corr.	-.010	-.010	-.012	-.012	-.007	-.011	.005	.002	.005
E_g (volts)	13.840	13.835	13.854	15.364	15.318	15.363	17.098	17.154	17.059
Avg.		13.843			15.348			17.104	

E_p	275			300		
T	40	50	60	40	50	60
1	18.52	18.67	18.55	20.00	20.05	20.00
2	18.52	18.61	18.52	20.05	20.05	20.00
3	18.50	18.64	18.51	20.025	20.05	20.00
4	18.52	18.63	18.50	20.00	20.05	20.10
5	18.50	18.66	18.55	20.05	20.00	20.00
6	18.52	18.67	18.53	20.025	20.10	20.95
7	18.53	18.68	18.52	20.00	20.05	20.00
8	18.53	18.66	18.54	20.00	20.00	20.10
9	18.53	18.67	18.53	20.05	20.05	20.00
10	18.54	18.63	18.54	20.025	20.10	20.05
Avg.	18.521	18.652	18.530	20.020	20.050	20.025
Corr.	-.021	-.028	-.021	-.025	-.025	- .025
E_g	18.500	18.624	18.509	19.995	20.025	20.000
Avg.		18.544			20.007	

Note: All grid voltages are negative.

VARIATION OF CRITICAL E_g WITH TEMPERATURE FOR THE 2051

E_p (volts)	50			75			100		
T (°C)	40	50	60	40	50	60	40	50	60
1	.96	.95	.98	1.24	1.23	1.25	1.44	1.40	1.45
2	.96	.96	.98	1.24	1.24	1.26	1.44	1.44	1.44
3	.95	.96	.97	1.24	1.25	1.27	1.44	1.44	1.46
4	.95	.96	.98	1.24	1.25	1.26	1.44	1.43	1.45
5	.95	.96	.97	1.24	1.25	1.26	1.44	1.42	1.45
6	.96	.95	.98	1.24	1.25	1.26	1.44	1.42	1.44
7	.96	.95	.98	1.25	1.25	1.26	1.43	1.42	1.46
8	.95	.95	.97	1.23	1.25	1.25	1.44	1.42	1.46
9	.96	.95	.97	1.24	1.25	1.26	1.43	1.42	1.47
10	.95	.95	.97	1.24	1.25	1.26	1.48	1.42	1.48
Avg.	.955	.954	.975	1.24	1.247	1.259	1.438	1.432	1.456
Corr.	-.016	.005	-.019	-.032	-.009	-.033	-.017	-.021	-.018
E_g(volts)	.937	.959	.956	1.208	1.238	1.226	1.421	1.402	1.438
Avg.		.951			1.224			1.420	

E_p	125			150			175		
T	40	50	60	40	50	60	40	50	60
1	1.63	1.62	1.65	1.80	1.79	1.81	1.96	1.96	1.97
2	1.64	1.62	1.65	1.80	1.80	1.81	1.97	1.96	1.95
3	1.64	1.62	1.66	1.79	1.80	1.80	1.97	1.96	1.97
4	1.63	1.61	1.65	1.79	1.79	1.81	1.98	1.96	1.97
5	1.63	1.63	1.65	1.79	1.80	1.80	1.97	1.96	1.97
6	1.64	1.61	1.66	1.80	1.80	1.81	1.97	1.95	1.97
7	1.64	1.61	1.65	1.79	1.79	1.80	1.96	1.96	1.97
8	1.63	1.60	1.64	1.80	1.79	1.81	1.96	1.97	1.97
9	1.64	1.62	1.65	1.79	1.79	1.80	1.96	1.95	1.97
10	1.64	1.62	1.64	1.79	1.79	1.80	1.97	1.96	1.97
Avg.	1.636	1.616	1.650	1.794	1.794	1.805	1.967	1.959	1.968
Corr.	-.022	-.030	-.028	-.005	-.011	-.005	-.018	-.020	-.018
E_g (volts)	1.614	1.586	1.622	1.789	1.783	1.800	1.949	1.939	1.950
Avg.		1.607			1.791			1.946	

VARIATION OF CRITICAL E_g WITH TEMPERATURE FOR THE 2051

E_p(volts)	200			225			250		
T (°C)	40	50	60	40	50	60	40	50	60
1	2.12	2.13	2.14	2.24	2.26	2.25	2.41	2.40	2.42
2	2.12	2.13	2.14	2.24	2.28	2.27	2.41	2.40	2.44
3	2.13	2.13	2.16	2.25	2.25	2.26	2.42	2.39	2.41
4	2.13	2.13	2.14	2.25	2.24	2.27	2.42	2.39	2.41
5	2.13	2.11	2.14	2.25	2.26	2.27	2.42	2.40	2.41
6	2.13	2.13	2.14	2.24	2.25	2.27	2.42	2.40	2.41
7	2.13	2.11	2.14	2.25	2.25	2.26	2.42	2.41	2.41
8	2.14	2.13	2.15	2.24	2.25	2.26	2.42	2.39	2.41
9	2.13	2.11	2.15	2.25	2.25	2.25	2.42	2.39	2.41
10	2.13	2.12	2.14	2.25	2.26	2.26	2.42	2.40	2.41
Avg.	2.129	2.123	2.144	2.246	2.255	2.262	2.418	2.397	2.414
Corr.	-.026	-.030	-.027	-.002	-.035	-.003	-.016	-.018	-.015
E_g (volts)	2.113	2.093	2.117	2.244	2.220	2.259	2.402	2.379	2.399
Avg.		2.108			2.241			2.393	

E_p	275			300		
T	40	50	60	40	50	60
1	2.56	2.56	2.56	2.71	2.69	2.72
2	2.57	2.56	2.56	2.71	2.69	2.71
3	2.58	2.54	2.57	2.72	2.70	2.72
4	2.57	2.56	2.57	2.72	2.70	2.71
5	2.58	2.54	2.57	2.71	2.70	2.72
6	2.57	2.57	2.56	2.72	2.71	2.71
7	2.57	2.55	2.56	2.72	2.70	2.71
8	2.58	2.56	2.57	2.72	2.70	2.71
9	2.57	2.56	2.57	2.73	2.70	2.72
10	2.57	2.57	2.56	2.71	2.70	2.72
Avg.	2.572	2.557	2.565	2.717	2.699	2.715
Corr.	-.024	-.206	-.023	-.031	-.022	-.031
E_g (volts)	2.548	2.531	2.542	2.686	2.677	2.684
Avg.		2.540			2.682	

Note: All grid voltages are negative.

APPENDIX III

Test Readings Taken to Determine Effect of Heater Voltage Variations

EFFECT OF A.C. AND D.C. HEATER VOLTAGE ON CRITICAL E_g FOR 884

E_p (volts)	50		100		150	
	A.C.	D.C.	A.C.	D.C.	A.C.	D.C.
1	.63	.68	.22	.23	.80	.85
2	.64	.66	.23	.21	.82	.84
3	.63	.67	.24	.24	.79	.85
4	.65	.66	.22	.22	.79	.83
5	.65	.66	.22	.21	.80	.82
6	.64	.68	.24	.24	.80	.84
7	.65	.66	.21	.21	.80	.82
8	.65	.67	.22	.22	.81	.81
9	.63	.67	.22	.22	.82	.83
10	.64	.67	.22	.22	.80	.84
Avg.	.641	.668	.224	.222	.803	.833

E_p (volts)	200		250	
	A.C.	D.C.	A.C.	D.C.
1	.22	.21	1.00	1.05
2	.22	.20	1.05	1.00
3	.19	.19	1.00	1.05
4	.21	.19	.95	1.00
5	.19	.18	.95	1.00
6	.21	.18	.95	.95
7	18	.19	.95	.95
8	.18	.17	.95	.95
9	.17	.19	.95	.95
10	.17	.17	1.00	.95
Avg.	.194	.187	.975	.985

Note: All grid voltages are negative.

EFFECT OF A.C. AND D.C. HEATER VOLTAGES ON CRITICAL E_g FOR THE 885

E_p (volts)	50		100		150	
	D.C.	A.C.	D.C.	A.C.	D.C.	A.C.
1	.25	.22	.36	.27	.46	.45
2	.24	.21	.36	.28	.46	.43
3	.24	.21	.35	.28	.46	.44
4	.25	.21	.36	.28	.47	.43
5	.25	.21	.36	.27	.47	.44
Avg.	.246	.212	.358	.276	.464	.438

E_p (volts)	200		220	
	D.C.	A.C.	D.C.	A.C.
1	.09	.08	.72	.70
2	.10	.09	.73	.71
3	.09	.09	.74	.71
4	.11	.08	.72	.70
5	.09	.08	.72	.70
Avg.	.096	.084	.726	.704

Note: All grid voltages are negative.

EFFECT OF A.C. AND D.C. HEATER VOLTAGE ON CRITICAL E_g FOR THE 6Q5G

E_p (volts)	50		100		150	
	A.C.	D.C.	A.C.	D.C.	A.C.	D.C.
1	.17	.15	.52	.52	.16	.20
2	.16	.15	.54	.53	.17	.18
3	.16	.14	.51	.54	.18	.18
4	.17	.14	.50	.50	.20	.18
5	.16	.15	.52	.51	.17	.19
6	.17	.15	.51	.51	.18	.21
7	.15	.14	.52	.52	.16	.19
8	.17	.15	.53	.51	.17	.19
9	.17	.13	.53	.52	.19	.18
10	.17	.15	.54	.54	.18	.19
Avg.	.165	.145	.522	.520	.176	.189

E_p (volts)	200		250		300	
	A.C.	D.C.	A.C.	D.C.	A.C.	D.C.
1	.25	.28	.13	.15	.95	.95
2	.27	.27	.14	.15	1.00	.95
3	.28	.29	.16	.16	1.00	.95
4	.29	.28	.11	.13	.95	.95
5	.28	.29	.13	.14	1.00	1.00
6	.26	.27	.14	.12	.95	.95
7	.27	.27	.15	.12	1.00	.95
8	.26	.29	.16	.15	1.00	1.00
9	.26	.28	.14	.12	.95	.95
10	.28	.30	.12	.11	1.00	.95
Avg.	.270	.283	.138	.135	.98	.96

Note: All grid voltages are negative.

EFFECT OF A.C. AND D.C. HEATER VOLTAGE ON CRITICAL E_g FOR THE 2051

E_p (volts)	50		100		150	
	A. C.	D.C.	A.C.	D.C.	A.C.	D.C.
1	.52	.51	.47	.48	.35	.37
2	.51	.52	.48	.49	.35	.36
3	.51	.51	.47	.49	.35	.36
4	.52	.51	.48	.48	.36	.35
5	.50	.52	.48	.49	.35	.35
6	.51	.51	.48	.48	.35	.36
7	.52	.52	.48	.48	.34	.35
8	.52	.52	.47	.48	.34	.35
9	.53	.53	.47	.48	.34	.35
10	.52	.52	.48	.48	.33	.35
Avg.	.516	.517	.476	.483	.346	.355

E_p (volts)	200		250		300	
	A.C.	D.C.	A.C.	D.C.	A.C.	D.C.
1	.65	.68	.44	.46	.71	.77
2	.65	.69	.43	.47	.74	.75
3	.66	.68	.42	.46	.75	.76
4	.66	.68	.43	.46	.74	.75
5	.67	.69	.43	.47	.74	.76
6	.66	.68	.42	.46	.74	.75
7	.66	.69	.44	.46	.74	.75
8	.67	.68	.43	.46	.75	.75
9	.67	.69	.44	.46	.74	.76
10	.66	.68	.43	.45	.75	.75
Avg.	.661	.684	.431	.461	.74	.755

Note: All grid voltages are negative.

APPENDIX IV

Test Readings Taken to Determine
Effect of D.C. Heater Voltage

VARIATION OF E_g FOR CHANGE IN E_f FOR THE 884

E_p (volts)		50			100			150	
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.54	.62	.67	.12	.18	.24	.47	.53	.63
2	.53	.62	.67	.12	.19	.24	.44	.55	.65
3	.55	.64	.65	.11	.20	.22	.44	.56	.66
4	.54	.62	.70	.11	.19	.26	.45	.50	.61
5	.56	.65	.70	.12	.18	.23	.45	.52	.62
6	.54	.61	.70	.12	.19	.25	.44	.56	.66
7	.55	.60	.69	.10	.19	.25	.47	.57	.61
8	.54	.62	.70	.11	.19	.23	.47	.55	.61
9	.56	.64	.69	.11	.18	.23	.47	.54	.64
10	.56	.63	.66	.10	.18	.24	.46	.51	.63
Avg.	.547	.625	.683	.112	.187	.239	.456	.539	.632
Corr.	-.017	-.026	-.029	-.004	0	-.002	-.016	-.022	-.027
E_g (volts)	.530	.599	.654	.108	.187	.237	.440	.517	.605

E_p (volts)		200			250			300	
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.65	.75	.85	.40	.50	.65	1.10	1.20	1.35
2	.70	.70	.85	.35	.50	.65	1.15	1.25	1.35
3	.65	.70	.90	.35	.45	.60	1.10	1.15	1.35
4	.65	.70	.85	.40	.50	.60	1.10	1.20	1.25
5	.65	.70	.90	.35	.50	.55	1.10	1.15	1.30
6	.65	.80	.90	.35	.505	.60	1.05	1.20	1.35
7	.70	.80	.90	.40	.50	.60	1.05	1.20	1.30
8	.65	.70	.85	.40	.50	.60	1.05	1.15	1.30
9	.70	.75	.90	.35	.50	.60	1.10	1.20	1.30
10	.70	.75	.85	.40	.50	.60	1.05	1.20	1.30
Avg.	.67	.735	.875	.375	.491	.605	1.085	1.19	1.315
Corr.	-.023	-.032	-.027	-.013	-.020	-.025	-.022	-.02	-.022
E_g (volts)	.642	.703	.848	.362	.471	.580	1.063	1.17	1.293

Note: Value of fine readings only noted. All readings are negative.

VARIATION OF E_g FOR CHANGES OF E_f FOR THE 885

E_p (volts)	25			50			75		
E_f (volts)	2.3	2.5	2.7	2.3	2.5	2.7	2.3	2.5	2.7
1	.13	.22	.37	.03	.15	.30	.38	.55	.71
2	.13	.23	.36	.03	.15	.29	.38	.56	.70
3	.13	.22	.37	.03	.15	.29	.38	.56	.70
4	.13	.21	.37	.02	.14	.28	.38	.54	.70
5	.13	.22	.38	.02	.15	.29	.38	.55	.71
Avg.	.13	.22	.37	.026	.148	.290	.38	.552	.704
Corr.	.006	-.001	-.012	.001	.003	-.005	-.013	-.023	-.030
E_g (volts)	.136	.219	.358	.027	.151	.285	.367	.529	.674

E_p (volts)	100			125			150		
E_f (volts)	2.3	2.5	2.7	2.3	2.5	2.7	2.3	2.5	2.7
1	.13	.31	.49	.27	.45	.63	.22	.42	.61
2	.13	.32	.48	.27	.45	.63	.22	.42	.62
3	.13	.32	.48	.26	.44	.64	.22	.42	.62
4	.13	.32	.48	.27	.45	.64	.22	.42	.61
5	.14	.31	.49	.27	.45	.64	.23	.42	.61
Avg.	.132	.316	.484	.268	.448	.636	.222	.42	.614
Corr.	.003	-.007	-.019	-.003	-.018	-.027	-.001	-.016	-.026
E_g (volts)	.135	.309	.465	.265	.430	.609	.221	.404	.588

Note: Value of fine readings only noted. All readings are negative.

VARIATION OF E_g FOR CHANGE IN E_f FOR THE 35

E_p (volts)		175			200			220	
E_f (volts)	2.3	2.5	2.7	2.3	2.5	2.7	2.3	2.5	2.7
1	.32	.53	.73	.15	.33	.60	.80	1.04	1.40
2	.33	.52	.73	.15	.33	.60	.79	1.04	1.41
3	.33	.53	.73	.16	.34	.60	.80	1.03	1.40
4	.33	.53	.72	.15	.34	.59	.80	1.04	1.41
5	.33	.52	.72	.16	.34	.60	.80	1.03	1.40
Avg.	.328	.526	.726	.154	.336	.598	.798	1.036	1.404
Corr.	−.008	−.021	−.031	.002	−.009	−.025	−.034	−.025	−.025
E_g (volts)	.320	.505	.695	.156	.327	.573	.764	1.011	1.379

E_p (volts)		240	
E_f (volts)	2.3	2.5	2.7
1	.75	1.25	1.55
2	.75	1.25	1.55
3	.70	1.25	1.50
4	.70	1.25	1.55
5	.725	1.25	1.55
Avg.	.725	1.25	1.52
Corr.	−.031	−.021	−.034
E_g (volts)	.694	1.229	1.486

Note: Value of fine readings only noted. All readings are negative.

VARIATION OF E_g FOR CHANGE OF E_f FOR THE 2051

E_p (volts)	25			50			75		
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.63	.67	.74	.04	.09	.13	.27	.32	.38
2	.62	.66	.73	.05	.10	.14	.29	.33	.39
3	.62	.67	.73	.06	.10	.15	.28	.34	.38
4	.62	.66	.73	.04	.09	.15	.29	.34	.38
5	.62	.66	.73	.05	.10	.15	.29	.34	.38
6	.63	.66	.73	.04	.10	.13	.28	.34	.39
7	.62	.67	.73	.04	.09	.14	.28	.34	.37
8	.61	.66	.73	.04	.09	.14	.28	.34	.38
9	.61	.66	.73	.04	.09	.13	.28	.34	.37
10	.61	.66	.72	.04	.09	.13	.28	.34	.38
Avg.	.619	.663	.730	.044	.094	.139	.282	.337	.380
Corr.	-.026	-.028	-.031	.002	-.025	.003	-.004	-.009	-.013
E_g (volts)	.593	.635	.699	.046	.069	.142	.278	.328	.367

E_p (volts)	100			125			150		
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.48	.50	.58	.66	.72	.75	.31	.36	.42
2	.48	.54	.59	.66	.72	.76	.31	.36	.41
3	.48	.54	.57	.66	.72	.77	.31	.36	.40
4	.48	.53	.58	.66	.71	.77	.31	.36	.42
5	.48	.52	.57	.66	.71	.75	.30	.37	.40
6	.48	.52	.58	.66	.71	.76	.30	.36	.42
7	.48	.52	.57	.67	.71	.76	.32	.36	.42
8	.47	.52	.58	.67	.70	.76	.30	.36	.41
9	.48	.52	.58	.66	.71	.76	.32	.36	.41
10	.48	.52	.57	.66	.71	.75	.30	.36	.41
Avg.	.481	.523	.577	.662	.712	.759	.308	.361	.412
Corr.	-.019	-.021	-.024	-.028	-.031	-.033	-.006	-.011	-.016
E_g (volts)	.462	.502	.553	.634	.681	.726	.302	.350	.396

Note: Value of fine readings only noted. All readings are negative.

VARIATION OF E_g FOR CHANGE OF E_f FOR THE 2051

E_p (volts)	175			200			225		
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.48	.53	.58	.63	.70	.75	.73	.80	.84
2	.48	.53	.59	.64	.70	.75	.72	.82	.86
3	.49	.53	.59	.64	.70	.74	.74	.80	.88
4	.47	.53	.58	.64	.70	.75	.74	.79	.84
5	.48	.53	.59	.63	.68	.76	.74	.80	.84
6	.46	.52	.58	.64	.70	.76	.75	.79	.86
7	.48	.53	.59	.63	.68	.76	.73	.79	.84
8	.48	.54	.58	.64	.70	.76	.73	.79	.86
9	.46	.52	.58	.62	.68	.76	.74	.79	.85
10	.45	.53	.58	.64	.69	.76	.75	.80	.84
Avg.	.469	.529	.584	.634	.693	.755	.737	.797	.851
Corr.	-.018	-.022	-.024	-.027	-.030	-.033	-.032	-.035	-.030
E_g (volts)	.451	.507	.560	.607	.663	.722	.705	.762	.821

E_p (volts)	250			275			300		
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.42	.46	.50	.54	.62	.66	.49	.54	.61
2	.40	.46	.50	.54	.62	.66	.50	.54	.61
3	.40	.45	.52	.54	.60	.66	.49	.55	.60
4	.40	.45	.51	.56	.62	.66	.50	.55	.62
5	.40	.46	.51	.54	.60	.66	.49	.55	.60
6	.40	.46	.52	.56	.63	.67	.48	.56	.61
7	.41	.47	.51	.57	.61	.67	.49	.55	.61
8	.41	.45	.53	.56	.62	.67	.48	.55	.60
9	.40	.45	.52	.55	.62	.68	.49	.55	.60
10	.40	.46	.52	.58	.63	.68	.49	.55	.60
Avg.	.404	.457	.514	.554	.617	.667	.490	.549	.606
Corr.	-.015	-.018	-.021	-.023	-.026	-.029	-.020	-.022	-.025
E_g (volts)	.389	.439	.493	.531	.591	.638	.470	.527	.581

Note: Value of fine readings only noted. All readings are negative.

VARIATION OF E_g FOR CHANGE OF E_f FOR THE 6J5G

E_p (volts)		25			50			75	
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.52	.56	.57	.16	.21	.27	.30	.34	.39
2	.52	.56	.58	.16	.21	.28	.30	.34	.38
3	.53	.56	.59	.17	.23	.26	.30	.34	.38
4	.53	.56	.60	.16	.22	.27	.30	.34	.38
5	.52	.56	.58	.17	.21	.25	.30	.34	.40
6	.51	.56	.58	.16	.21	.26	.31	.36	.38
7	.52	.56	.57	.17	.20	.25	.30	.34	.39
8	.51	.56	.60	.19	.22	.25	.31	.36	.39
9				.19	.24	.27	.30	.35	.39
10							.30	.36	.40
Avg.	.52	.56	.584	.169	.217	.263	.302	.347	.388
Corr.	-.021	-.023	-.024	.002	0	-.003	-.005	-.010	-.014
E_g (volts)	.499	.537	.560	.171	.217	.260	.297	.337	.374

E_p (volts)		100			125			150	
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.51	.56	.60	.52	.58	.65	.18	.22	.26
2	.50	.55	.61	.55	.59	.63	.17	.21	.27
3	.53	.58	.63	.54	.60	.64	.20	.24	.27
4	.53	.57	.64	.54	.59	.66	.18	.23	.28
5	.53	.57	.60	.54	.59	.65	.20	.24	.28
6	.54	.59	.65	.54	.59	.65	.18	.23	.28
7	.54	.58	.63	.55	.61	.64	.19	.24	.29
8	.54	.59	.63	.55	.61	.65	.18	.25	.29
9	.54	.59	.65				.18	.23	.28
10							.20	.24	.29
Avg.	.529	.575	.627	.541	.594	.647	.186	.233	.279
Corr.	-.021	-.024	-.026	-.022	-.025	-.027	.001	-.002	-.004
E_g (volts)	.508	.551	.601	.519	.569	.620	.187	.231	.275

Note: Value of fine readings only noted. All readings are negative.

VARIATION OF E_g FOR CHANGE OF E_f FOR THE 6J5G

E_p (volts)		175			200			225	
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.18	.21	.25	.30	.35	.41	.27	.33	.37
2	.18	.22	.26	.29	.36	.38	.26	.32	.40
3	.17	.23	.28	.31	.35	.38	.26	.31	.35
4	.19	.24	.28	.31	.35	.37	.26	.32	.35
5	.18	.23	.29	.32	.35	.39	.26	.31	.39
6	.21	.23	.26	.29	.34	.38	.28	.34	.39
7	.19	.24	.26	.32	.34	.38	.28	.34	.40
8	.17	.20	.24	.29	.35	.40	.27	.33	.39
9	.17	.23	.27				.28	.34	.39
10							.26	.32	.39
Avg.	.182	.225	.265	.303	.349	.385	.268	.326	.382
Corr.	.001	-.001	-.003	-.005	-.010	-.014	-.003	-.008	-.013
E_g (volts)	.183	.224	.262	.298	.339	.371	.265	.318	.369

E_p (volts)		250			275			300	
E_f (volts)	6.1	6.3	6.5	6.1	6.3	6.5	6.1	6.3	6.5
1	.06	.13	.15	.63	.67	.70	1.00	1.05	1.10
2	.08	.14	.18	.59	.61	.64	1.00	1.05	1.10
3	.07	.12	.16	.59	.64	.68	1.00	1.05	1.10
4	.10	.15	.18	.61	.63	.70	1.00	1.05	1.10
5	.10	.16	.19	.61	.66	.70	1.00	1.05	1.10
6	.13	.17	.21	.62	.67	.70			
7	.13	.18	.23	.64	.68	.70			
8	.13	.18	.22	.63	.66	.72			
9				.64	.67	.70			
10									
Avg.	.098	.154	.190	.618	.653	.694	1.00	1.05	1.10
Corr.	.005	.002	0	-.026	-.028	-.030	-.025	-.025	-.022
E_g (volts)	.103	.156	.190	.592	.625	.664	.975	1.025	1.078

Note: Value of fine readings only noted. All values are negative.

VITA

Fred Earl [illegible], Jr., was born in Altoona, Pennsylvania, on April 14, 1914, the son of Fred E. and Helen L. [illegible].

His early education was obtained in the secondary schools of Maryland, Georgia and Pennsylvania. Upon graduation from high school in 1932, he entered the Lock Haven State Teachers College, Lock Haven, Pennsylvania, where he studied until he received an appointment to the United States Naval Academy in the spring of 1934. He graduated from this institution on June 2, 1938, with a Bachelor of Science degree.

Upon graduation from the U. S. Naval Academy, he entered the United States Navy and carried out the duties of a Line Officer rising to the rank of Commander, U. S. Navy. In the summer of 1945 he was selected for a postgraduate course in Ordnance Engineering. In July of that year he began his studies in Guided Missile Ordnance at the Naval Postgraduate School, Annapolis, Maryland. At the end of one year, he was sent to The Johns Hopkins University, Baltimore, Maryland, to continue his studies.

He is married and has one child.

DATE DUE

Thesis 12618
M185 McEntire
The firing characteristics of certain small thyratrons.

Thesis 12618
M185 McEntire
The firing characteristics of certain small thyratrons.

thesM185
The firing characteristics of certain sm
3 2768 001 88433 1
DUDLEY KNOX LIBRARY